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User Feedback on RFID and Integrated Flightline Data for Maintenance Decisions

Jennie J. Gallimore

HumanWise, Inc.
1342 North Church Court
Bellbrook, OH 45305

Laurie Quill

University of Dayton Research Institute
Human Factors Group
300 College Park
Dayton, OH 45469

Ron Cagle
Jessica Gruenke
Chris Hosman
Elizabeth Matthews

GRACAR Corporation
714 Monument Avenue, Suite 204
Dayton, OH 45402

Paul Faas
Jason Seyba
Ian Young

Air Force Research Laboratory
Wright-Patterson AFB, OH 45433-7604

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User Feedback on RFID and Integrated Flightline Data for Maintenance Decisions

Jennie J. Gallimore[1], Laurie Quill[2,] Ron Cagle[3], Jessica Gruenke[3], Chris Hosman[3], Elizabeth Matthews[3],

Paul Faas[4], 2nd Lt. Jason Seyba[4], Lt Ian Young[4]

[1] HumanWise, Inc., Bellbrook, OH 45305, 937-271-5403, JGallimore@HumanWise.Com

[2] UDRI, Dayton, OH 45469

[3] GRACAR Corporation, Dayton, OH 45402

[4] Air Force Research Laboratory AFRL/HEAL, Wright-Patterson AFB, OH 45433-7604

ABSTRACT

Creating Agile Combat Support (ACS) requires real time integrated information systems to support human decision making. Real time sensing technologies are being investigated to improve logistics support. The purpose of this study was to investigate integrated Radio Frequency Identification/Real Time Location System (RFID/RTLS) technology with flightline information for improved decision making for flightline maintenance operations. A simulation was developed that integrated information related to the flightline with RFID location information (Smart Systems). A simulated field test was conducted to compare the Smart Systems integrated condition with an off-the-shelf RFID technology and a baseline condition for providing support for the fix or swap decision.

Keywords: RFID, logistics, flightline maintenance, decision making, human factors

Introduction

A complex arena within the U.S. Military logistics support is flightline aircraft maintenance. The overall goal of the maintenance unit is to prepare aircraft to meet scheduled mission sorties. Logistics and sortie production mission success depends on effective use of resources (people, equipment, supplies, and information). However, the flightline maintenance operational environment has limited cross echelon situational awareness. Data capture and decision analysis are largely manual processes. There remains very little insight to wing-level sortie production capability. Decision making is still limited by the ability to collect and assimilate data into reasoned, actionable information. Information technology systems designed to support operations are often standalone systems that do not share data. Personnel can be overwhelmed with too much data to effectively plan and allocate logistics resources. Personnel need a means to identify the impact of their logistics actions on operational capability [2].

RFID and RTLS are examples of off-the-shelf technologies with potential to improve the maintenance process [4]. RFID/RTLS technologies with active tagging have the potential to improve awareness related to resource location by showing where things are. Although off-the-shelf RFID/RTLS technology provides immediate location information on tagged resources, and allows a decision maker to easily find these resources; in its stand alone form it is merely another information stovepipe. So while near real time information is available, it will not necessarily improve flightline decision making. If a required piece of equipment is sitting on the flightline, it is not possible to tell, within the current applications, what it is doing out there. It might be in use, out of fuel, awaiting a high priority task to begin, or ready for re-assignment. This type of information can be provided through customization of the off-the-shelf RFID/RTLS products. The challenge with sensor technologies is to provide the correct information, at the right time, in the right format to improve human decisions and system performance.

A research project funded by the U.S. Air Force called Smart Systems is underway to develop requirements that employ technologies and techniques to autonomously collect and fuse critical data in order to create decision quality information and effectively present information to support tasks performed by flightline logistics and operations decision-makers[3]. This paper discusses one research study conducted under this effort.

Objective

The objective of this research was to evaluate user opinions on the use of enhanced data streams and integrated information for providing support for making fix/swap decisions. A simulation study was conducted to compare an integrated information condition (Smart Systems) with an off-the-shelf RFID technology condition (WhereNet) and a Baseline (current capabilities). The study was designed to determine if users prefer the Smart Systems integrated information approach to off-the-shelf RFID/RTLS (WhereNet) and current practice.

Method
A simulation was developed by creating scenarios in which an aircraft on the flight schedule has a maintenance problem. Expeditors (e.g., participants) analyze the problem and determine whether the aircraft can be fixed to meet the schedule or if a swap is necessary. They must solve problems and allocate resources in order to meet sorties.

Experimental Design
The experimental design was a within-subject full factorial design with three conditions: Baseline, WhereNet and Smart Systems. The Baseline condition was similar to how Expeditors currently carryout their task. They were provided paper references and used a radio for all communications. The WhereNet condition included all the same paper references provided in the Baseline condition as well as the WhereNet software which provided location of flightline resources (equipment and personnel). This off-the-shelf system does not provide any decision support or integration of information. All communication was via radio. The Smart Systems condition was represented through a computer system and included decision support as well as monitoring, location, and availability of resources. The radio was available for communication, but was used primarily for the receipt of messages.

Upon completion of each condition participants filled out a questionnaire in which they were asked to rate their agreement with fifteen statements on scale from 1 to 7 (1 strongly disagree, 7 strongly agree). They were also asked to rank the three conditions on five purposes: monitoring resources, locating resources, identifying resource availability; tracking time associated with resources, and making the fix/swap decision.

Participants
Fifteen maintenance personnel from four airbases participated in the study. All participants had experience as an Expeditor or Production Supervisor (ProSuper, supervises the Expeditor) within the past five years and had performed those duties within the past 6 months. Nine of the participants were experienced with airlift aircraft and six with fighter aircraft. The participants had an average of 18 years experience.

Apparatus
Three computers running Windows XP were used for the study. A desktop computer ran the Smart Systems server and the Oracle server with the database. This machine was a Pentium 4 with a 3 GHz processor and 512 megabytes of random access memory (RAM). A second Pentium 4 desktop computer with a 2.4 GHz processor and 1 gigabytes of RAM ran the WhereNet server. The third computer was a laptop that the participant used to interface with the servers. The laptop was a Pentium 4 with a 1.4 GHz processor and 512 megabytes of RAM. Internet Explorer was the browser used to communicate with the servers. The computers were linked together using two hubs.

Two Motorola Radius P1225 Portable Two Way Radios were used for communication. Participant used the radio to contact various maintenance personnel (played by researchers).

Experiment Stimuli and Scenarios
The stimuli consisted of an overall scenario depicting the deployed environment, base conditions, and aircraft missions. A base map was provided depicting the flightline with parking locations, aircraft maintenance units, ready line and other relevant base locations.

Baseline Stimuli: Baseline stimuli consisted of paper information sheets which included a personnel roster, equipment list, and a daily status sheet that included each aircraft with their status, and flight schedule.

WhereNet Stimuli: WhereNet stimuli consisted of the same paper information sheets used in the Baseline condition and WhereNet software. Figure 1 illustrates the report view screen available in WhereNet. A second map view was also available allowing the user to see geographic location of resources.
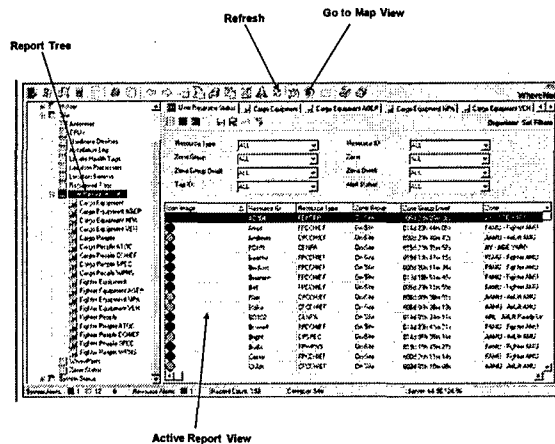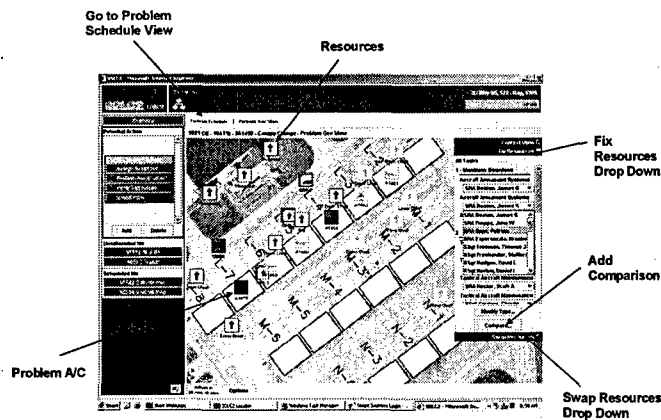
Figure 1: WhereNet Report View

Figure 2. Smart Systems Problem Specific Geographic View

Smart Systems Stimuli: During this condition participants were not given any paper materials. The computer system provided aircraft status and location, daily flying schedules, personnel and equipment resources and their locations, tasks necessary to fix the broken aircraft, tasks necessary to swap an aircraft, time to complete fix tasks, time to get resources to the fix site, resource types necessary to complete tasks, specific resources assigned to tasks, and a recommendation to fix or swap an aircraft. Figure 2 illustrates the geographic view of Smart Systems. A schedule view was also available.

Scenarios

Four scenarios were created and were designed to have three triggers. Time would advance between each trigger. At the beginning of the scenario, the participant would monitor the flightline (review the current state of the aircraft and flightline). The first trigger was an aircraft maintenance problem. The problem has already been assessed and verified by a specialist. The participant works the problem, decides to fix or swap, provides estimates to time, and begins the fix. After completing this trigger, a second and third trigger occurred in which a resource had to be replaced. One trigger was a personnel resource and one was an equipment resource.

Four scenarios were created, each with a different aircraft problem. Scenarios were adapted for either fighter or airlift participants. The scenarios included the following: 1) Gland Nut Change, 2) Cockpit Glass Change (airlift version) and Canopy Glass Change (fighter version), 3) Fuel Leak and 4) Prop Change (airlift version) and Engine Compressor Stall (fighter version). The Prop Change/Engine Compressor Stall scenario was used for training.

Procedure

The study conditions were counter-balanced across the participants. Each condition started with a training session. The radio communication system was briefly explained, including the call signs. For the Smart Systems and WhereNet conditions the participant was trained on how to use the software. After technology training the participant was given time to interact with the technology until they felt comfortable. The second part of training allowed the user to step through a sample scenario. During the study the participant was encouraged to think aloud as they were making decisions (verbal protocol). Additionally, the Lead Experimenter asked question probes at appropriate times to capture information such as comfort with the technology, strategies used for making decisions, and estimates of time associated with movement on the flightline.

Results

Rating Results: The post-condition questionnaire asked participants to rate their agreement with fifteen statements on scale from 1 to 7 (1 strongly disagree, 4 neutral, 7 strongly agree) (see Table 1). An overall analysis averaging ratings across all fifteen statements was calculated. Additionally, each individual statement was evaluated across the three conditions. In all cases, an Analysis of Variance (ANOVA) with a criterion level of 0.05 was conducted with a Greenhouse-Geisser correction. (Note that Greenhouse-Geisser is a very conservative correction.) Paired comparisons were also conducted when effects were significant using Tukey's test. Table 1 shows the statistical results and mean ratings for each condition. Data for one participant was dropped due to missing data for several questions.

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When collapsing across all 15 agreement statements (F (1,13) =8.98, $\underline{p}$ =.0103), there was statistically significant difference in ratings between Smart Systems and Baseline, and WhereNet and Baseline. Examining each statement separately (Table 1 below), 8 of the 15 statements showed no significant differences among conditions. Of the 7 statements that showed statistical significance, Smart Systems was rated higher than Baseline. Four of the 7 statements indicated WhereNet was rated higher than Baseline. Smart Systems was not rated higher than WhereNet for any of the 7 statements.

Statements 13-15 all dealt with aspects related to situation awareness (noticing, understanding, and predicting) [1] and were also collapsed and analyzed for overall situational awareness assessment (F(1,13) = 4.96, p=.0442). Results indicated that Smart Systems was rated significantly higher than Baseline. However, when looking at each of these questions individually we see that only one aspect reaches statistical significance - predicting. Statements related to noticing and understanding showed no difference among the ratings. We can not conclude, therefore, that situation awareness is improved for all aspects of SA.

Statements 10-12 dealt with human performance with the tools (usability, usefulness, and impact to decision making), these statements were collapsed to analyze for overall human performance with the tool. Results were not statistically significant.

Table 1: Mean Ratings with Tukey Groupings*

Statement (1 – Strongly Disagree, 7 – Strongly Agree): F values, p, and Condition Means SS= Smart Systems, WN = WhereNet, BL = Baseline, **Bold p** indicates significant findings at the .05 level	
1. There was enough information at all times to carry out my tasks and make decisions. F (1,13) = 1.28, p= .2783 SS=6.43 WN=5.86 BL=5.64	9. The technology improved my resource utilization because I know where all my resources were. F(1,13)=11.41, **p =.0049** SS=6.57 (A) WN=5.93 (A) BL=4.62 (B)
2. There was enough information to monitor the status of resources on the flightline. F(1,13)=7.68, **p =.0159** SS=6.78 (A) WN=6.07 (A, B) BL=5.21 (B)	10. The technologies provided were usable. F(1,13)=3.54, p =.0825 SS=6.50 WN=6.07 BL=5.72
3. I was able to determine where my equipment resources were. F(1,13)=6.21, **p =.0270** SS=6.64 (A) WN=6.57 (A) BL=5.00 (B)	11. I was provided with useful decision support. F(1,13)=2.05, p =.1758 SS=6.36 WN=6.21 BL=5.50
4. I was able to determine where my personnel resources were. F(1, 13)=9.39, **p =.0090** SS=6.14 (A) WN=6.64 (A) BL=4.57 (B)	12. Decision support as provided through this technology would positively impact flightline maintenance. F(1,13)= 2.71, p =.1236 SS=6.21 WN=6.21 BL=5.35
5. I was able to identify the availability of my equipment resources. F=(1,13)=6.44, **p =.0248** SS=6.43 (A) WN=6.28(A) BL=4.78 (B)	13. It was easy to notice when there were problems with aircraft. F(1,13)=3.15, p =.0993 SS=6.14 WN=4.71 BL=5.00
6. I was able to identify the availability of my personnel resources. F(1, 13)=4.39, p =.0561 SS=6.07 WN=6.07 BL=4.64	14. When problems occurred, it was easy to understand the status and location of resources needed to address the problem. F(1,13)=3.03, p =.1053 SS=6.57 WN=6.21 BL=5.57
7. I was able to determine what specific tasks needed to be accomplished. F(1,13)=1.028, p =.3291 SS=6.43 WN=6.07 BL=5.92	15. When problems occurred, I was able to predict whether I could meet the flying schedule. F(1,13)=5.06, **p = .0424** SS=6.00 (A) WN=5.64 (A, B) BL=4.71 (B)
8. I was able to track time associated with the movement of resources on the flightline. F(1,13)=5.78, **p = .0318** SS=6.36 (A) WN=5.29 (A, B) BL=4.79 (B)	Collapsing across all 15 statements combined: F(1,13) = 8.98, **p = .0103** SS=6.37 (A) WN=5.99 (A) BL=5.13 (B)

* Letters next to means indicate Tukey Groupings. Means with the same letter are not significantly different.

Ranking Results: All 15 participants provided a rank order (1=first preference) of the three conditions for five purposes: monitoring resources, locating resources, identifying resource availability; tracking time associated with resources, and making the fix/swap decision. The rankings for all five questions were collapsed and analyzed for differences. Also, the mean rankings for each ranking question were evaluated across the three conditions. In all cases, an ANOVA with a criterion level of 0.05 was conducted with a Greenhouse-Geisser correction. Paired comparisons were also conducted when effects were significant using Tukey's test. Results are presented in Table 2.

Table 2: Mean Rankings and Tukey Groupings*

Preference Rating: 1=first Preference, 3= third preference	
Ranking Statement and F test	**Means and Tukey Groupings**
Monitoring Status of Resources $F(1,14) = 8.34$, $p = .0119$	SS = 1.33 (A) WN = 2.53 (B) BL = 2.13 (B)
Locating Resources $F(1,14) = 5.44$, $p = .0351$	SS = 1.40 (A) WN = 2.20 (B) BL = 2.40 (B)
Identifying Resource Availability $F(1,14) = 3.90$, $p = .0683$	SS = 1.47 (A) WN = 2.20 (A, B) BL =2.33 (B)
Tracking Time Associated with Resources $F(1,14) = 11.20$, $p = .0048$	SS = 1.33 (A) WN = 2.66 (B) BL = 2.00 (A, B)
Making Fix/Swap Decision $F(1,14) = 9.86$, $p = .0072$	SS = 1.53 (A) WN = 2.73 (B) BL = 1.73 (A)
Collapsing across all Ratings $F(1,14) = 9.52$, $p = .0080$	SS = 1.33 (A) WN = 2.46 (B) BL = 2.12 (B)

* Letters next to means indicate Tukey Groupings. Means with the same letter are not significantly different.

When collapsing across the five statements there was a statistically significant difference between Smart Systems and WhereNet and between Smart Systems and Baseline. There was no difference between WhereNet and Baseline. Examining results for each ranking separately shows differences between the three conditions varied based on the ranking statement. There was a statistically significant difference between Smart Systems and WhereNet for 4 of the 5 statements (**Monitoring, Locating, Tracking time and Fix/swap**) with Smart Systems being ranked higher. There was a significant difference between Smart Systems and Baseline for 3 of the 5 statements (**Monitoring, Locating and Identifying**) with Smart Systems being ranked higher. Ranking was significantly different between WhereNet and Baseline only when making the **fix/swap** decision. In this case Baseline was ranked higher. These results suggest that there was little difference between Baseline and WhereNet conditions in terms of preference.

Discussion
Participants provided their opinions on the use of enhanced data streams using RFID resource location information integrated with flightline information (Smart Systems), off-the-shelf RFID resource location without information integration (WhereNet) and current practice (Baseline). Results from the rankings indicated that Smart Systems was preferred to WhereNet and Baseline. When ranking the three conditions, there was only one difference between Baseline and WhereNet conditions. Baseline was ranked higher than WhereNet for making the fix/swap decision. However, WhereNet was rated higher than Baseline in four of the 15 rating statements (Table 1). These statements were related to location of equipment and personnel, availability of equipment, and improved resource utilization. It should be noted that WhereNet only provides information about location, not availability of resources. However location is sometimes an indication of availability, e.g., if personnel are located in the AMU the expeditor may assume they are available.

For rating statements there were no differences between Smart Systems and WhereNet, yet Smart Systems was ranked higher in terms of preference. Users commented that they felt interacting with WhereNet was somewhat difficult; however they did like the ability to filter and sort resources.

The results indicate that developers must consider how enhanced data streams (such as location of resources) can be integrated with existing information to support user tasks and decisions within the context of their work. Location information as a stand alone system (WhereNet) was not preferred.

Participants were asked what data sensors could collect that would impact flightline decisions. They indicated that information such as base supplies on the Quick Reference List, equipment status (broken, in use, not in use), fuel level, oil level, equipment temperature, liquid oxygen level, battery level, and oil levels would be useful. All of these items were reiterated at all field test locations. Participants said this information could aid in making cannibalization and fix/swap decisions. RFID/RTLS and sensor information could help participants prioritize tasks and resources.

Tagging every resource on a flightline could be overwhelming. Participants verbalized that WhereNet had too much information at times because everything was tagged and the most critical information was not readily accessible. Participants suggested tagging Low Density/High Demand (LD/HD) items. Participants indicated there are resources either in supply or frequently used or borrowed that would be more important to tag.

Many participants indicated that the biggest difficulty they have, particularly as ProSupers and Expeditors, is finding people. Many indicated that a large amount of time is wasted searching for personnel. They indicated that tagging identifications could be especially useful when you needed someone with specific certifications quickly. One challenge to tagging personnel resources is that the Expeditor and ProSuper are not always the direct supervisor of all flightline personnel. They do not necessarily know what task a Specialist has been assigned. Other challenges are social including the concern with privacy as well as issues of trust. Many bases, particularly Guard and Reserve Units, have unions and the civilian culture would be more resistant to RFID tagging. However, during deployed missions this is not an issue and may be extremely beneficial during wartime operations.

Conclusions
The next phase of this research includes development of smart sensors that will provide equipment status indication along with location. The prototypes for the sensors are complete and the sensors will be deployed to an Air Force base location for demonstration and data collection. Additionally the simulation is being updated to add real world complexity with multiple flightline problems, multiple decisions and cascading effects. We are investigating the fusion of information to provide different decision makers with a shared vision to support collaborative decision making. The advantage of correctly fusing data from sensor technologies into complex operations is that decision makers will be more able to sense and then respond to issues or problems before they affect the ability to fulfill a mission, thus providing a more agile and responsive operation.

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